Defense Solutions Division

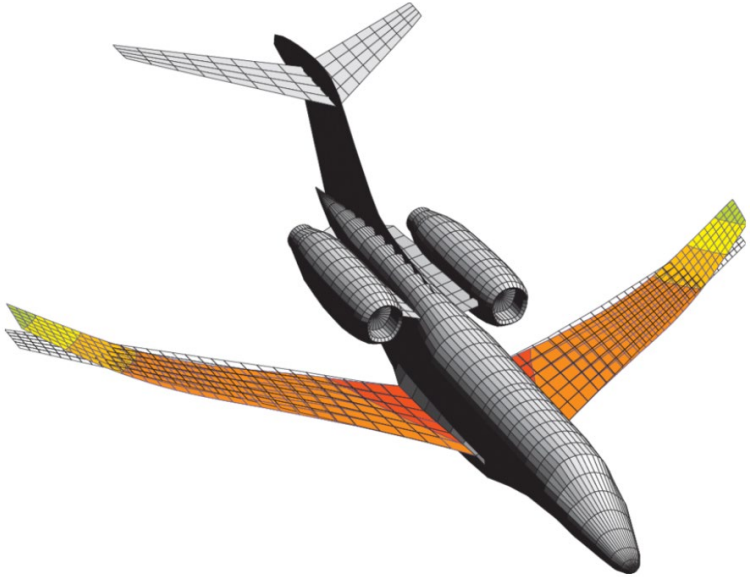
Optimizing PCM Bandwidth Usage in Flight Test by Real-time Data Analysis During Flight

ITEA-2022

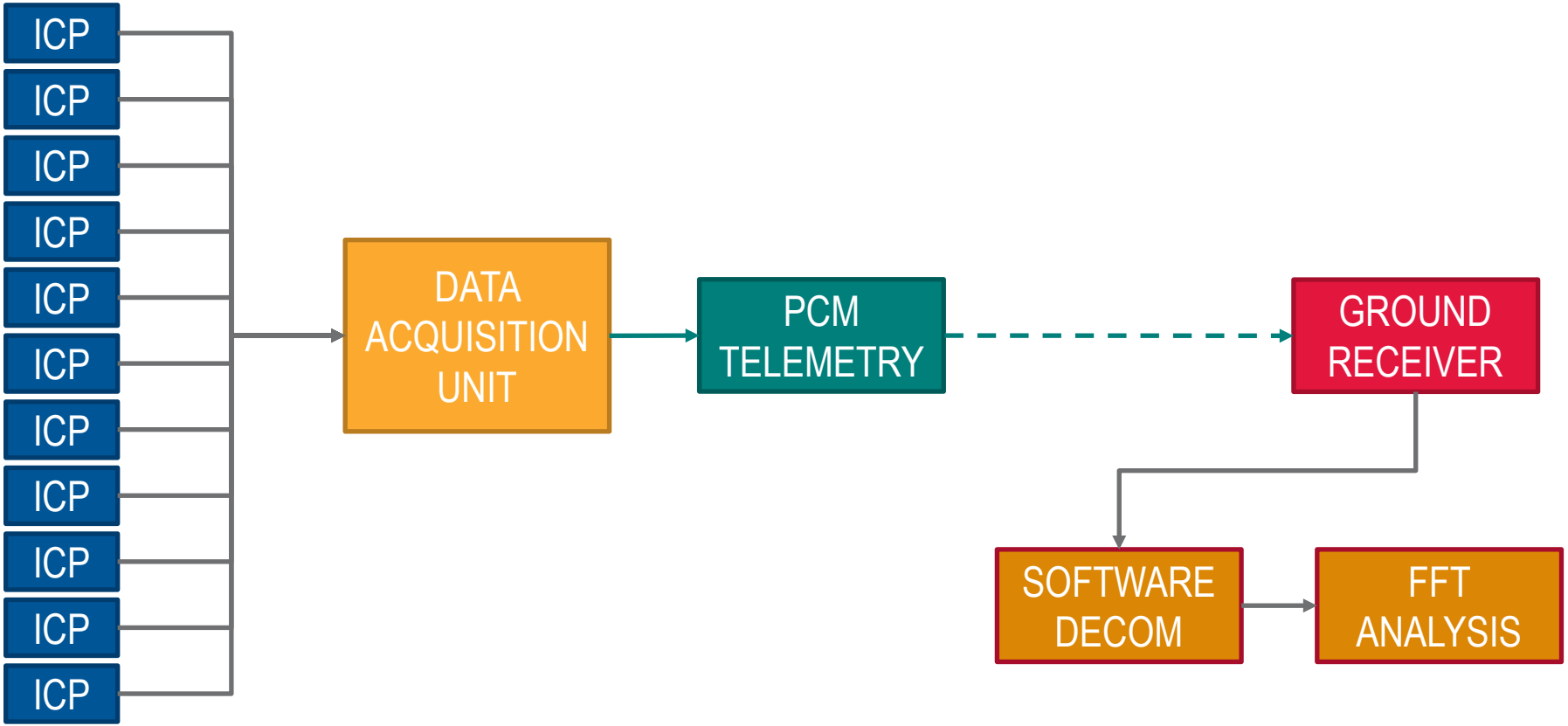
- FFT analysis / Balancing act
  - Channel FS and FC
  - Max Detectable Frequency
  - No FFT Samples
  - FFT Resolution
  - Time to Gather FFT Samples
  - Windowing Function
  - FFT Frequency Spread (Cluster Size)
- Challenges of designing FFT into the DAU user module
  - Raw Sample Storage / Buffering
  - DC Offset Removal
  - FFT Processing
  - Power Consumption
  - How to Present Results
    - Peak Detect
    - FOI
- PCM Bandwidth Saving

Why Measure Vibration?

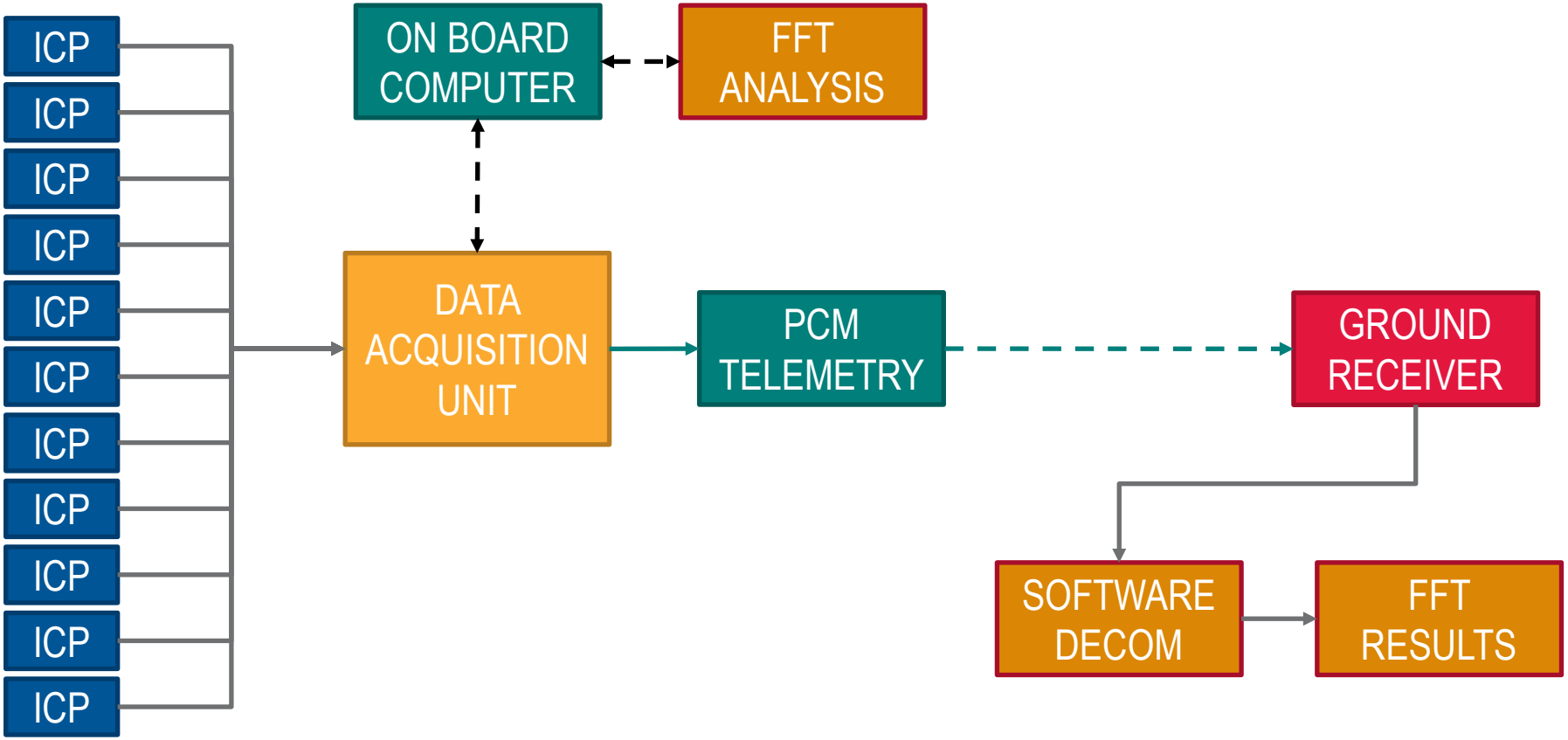
- During flight test applications, it is critical to understand and quantify the vibration frequencies experienced by the airframe during an actual flight.
- The expected vibration comes from computer models of the airframe and reflect the extremes of vibration the airframe is designed to withstand throughout the life-time of the airframe.
- The actual vibration data is compared to flight qualification random vibration test standards and are typically substantially lower than the random vibration test curves.



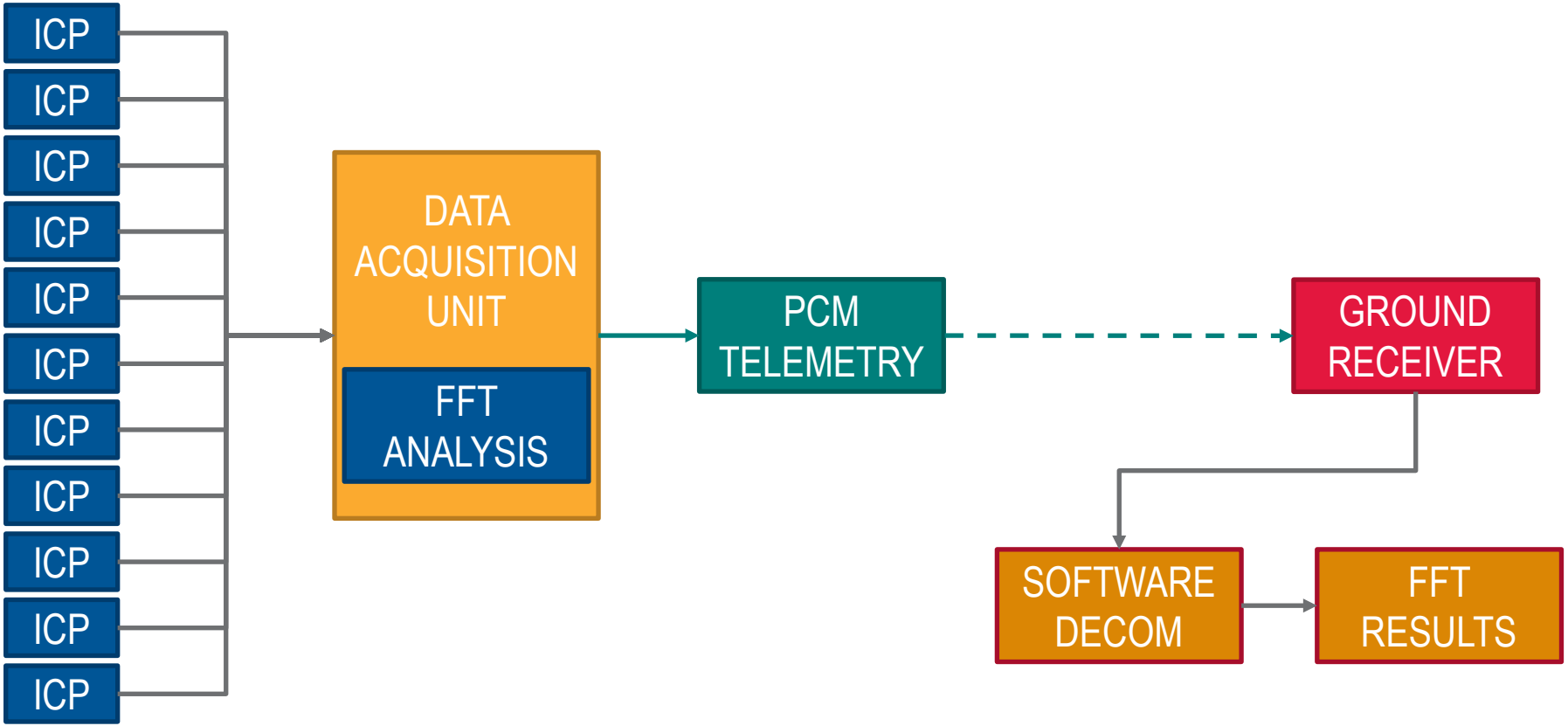
Vibration Measurement Methods - Traditional



Vibration Measurement Methods – Analysis in the Air - Today



Vibration Measurement Methods – Analysis in the Air – GOAL!

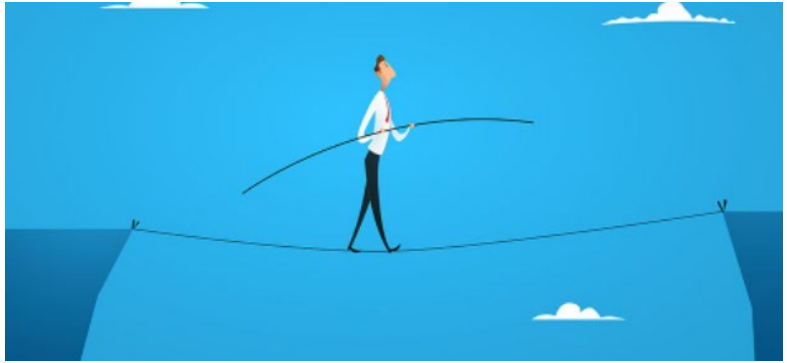


Vibration Measurement – Considerations:

- **Sensor Choice:**
  - Know the expected Vibration Frequency Range
  - Choose Sensor that meets the bandwidth requirements
- **Data Acquisition System:**
  - Must meet the required Vibration bandwidth
  - Filtering / Filter cut-off
  - Channel Density
  - Consider Full System Architecture
  - Telemetry Bandwidth Available
  - PCM Frame Structure
- **Example:**
  - NASA F-15B Flight Test Fixture II Test Bed
  - Requirement: 15Hz to 1325Hz

FFT Measurement – Balancing Act:

- **Channel Sample Rate & Filter Cut-off:**
  - Bandwidth must be > Max Frequency
  - Filter Cut-off must be > Max Frequency
  - (FS: 8192Hz, FC: 2048Hz)
- **# FFT Samples (FFT Block Size):**
  - The number of samples takes for each FFT measurement is critical
  - Drives the FFT Resolution & Max Detectable FFT Frequency



FFT Measurement – Balancing Act:

- **FFT Resolution:**
  - Sample Rate / FFT Block Size
    - If the Frequencies of Interest are close together higher resolution would be required.
    - If the Frequencies of interest are spaced apart lower resolution might be acceptable
- **Number of FFT Points (BINs):**
  - FFT Block Size / 2
    - Each point will contain a signal power at a specific frequency
    - Larger Block gives you more coverage
- **Example:**
  - NASA F-15B Flight Test Fixture II Test Bed
  - Requirement: 15Hz to 1325Hz
  - FS = 8192Hz
  - FC = 2048Hz
  - FFT Points:
    - 16K Resolution: 0.5Hz
    - 32K Resolution: 0.25Hz
    - 64K Resolution: 0.125Hz

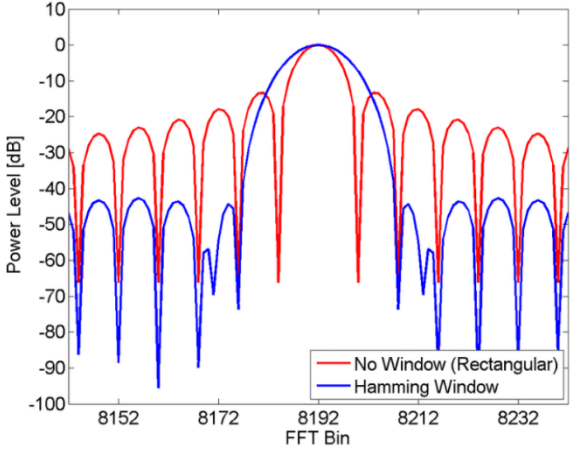
FFT Measurement – Balancing Act:

- **Max Detectable FFT Frequency:**
  - Frequency of Final BIN in the FFT Analysis
    - Must ensure that the FFT Resolution and the number of FFT Points > the max expected frequency
- **Time to Gather Samples:**
  - At Higher FS and Lower FFT Block size you gather the samples faster
  - At Lower FS and Larger FF Block size it take longer to gather the samples
- **Time to Process the FFT Samples:**
  - More Samples takes more Time

- **Example FFT Maths:**
  - Bock Size vs Res vs Max F vs Time
    - 16K
      - Res: 0.5Hz
      - #BINs: 8192
      - Max Freq: 4095.5Hz
      - Time: 2 Seconds
    - 32K
      - Res: 0.25Hz
      - #BINs: 16384
      - Max Freq: 4095.75
      - Time: 4 Seconds

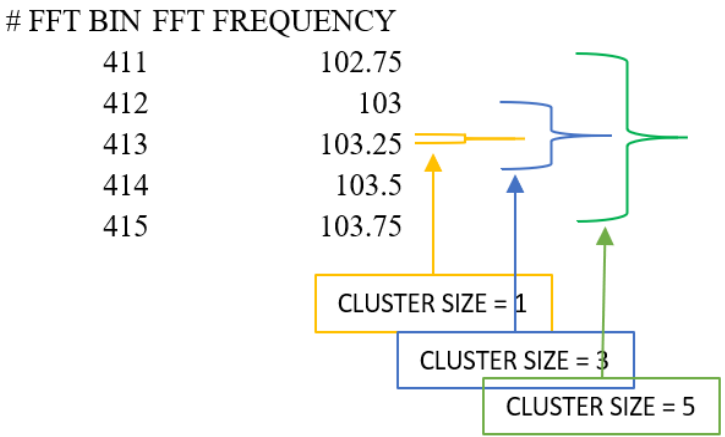
FFT Measurement – Balancing Act:

- **Windowing Function:**
- FFT transforms of a pure sinewave signal assumes that the data is one period of a periodic signal. For the FFT, both the time domain and the frequency domain are circular topologies, so the two endpoints of the time waveform are interpreted as though they were connected. When the measured signal is periodic and an integer number of periods fill the acquisition time interval, the FFT turns out fine as it matches this assumption.
- In reality, the measured signal is not an integer number of periods, not a pure sinewave, and this introduces discontinuities in the signal that appear as high-frequency components. These can be reduced by applying "windowing" functions to the FFT analysis.
- Many windowing functions are available in FFT analysis, but Hamming and Rectangular windows are most common.
- Hamming: Better for Frequency Resolution
- Rectangular: Better for Amplitude Accuracy



FFT Measurement – Balancing Act:

- **Frequency Spread:**
- Typically, vibration signals are not pure sinewave signals, where all the signal's power is concentrated into a single frequency point in the spectrum. It is more common that the true power of a specific frequency is spread across a number of points, all close together.
- To this end, reading the power at a single frequency BIN may not accurately reflect the power seen. It may be more beneficial to read the power across several sequential BINs and average the reading across those points.
- Breaking the FFT results into clusters or groups and calculating the power seen on that group can give a more accurate result, provided that the members of said group are close together.



Designing FFT into the Data Acquisition Module:

- **Challenges:**
  - Needs to support ICP functionality
    - High Channel Density
    - Constant Current Excitation
    - High Bandwidth
  - Raw Sample Storage
    - Needs to be able to store the Raw Samples, before the FFT can be run & while the FFT is running.
    - Needs enough space for sampling at max rate on all channels
  - Timestamp of the FFT Blocks
    - To correlate the results back to the raw samples.

Designing FFT into the Data Acquisition Module:

- **Challenges:**
  - DC-Offset Removal
    - DC (0Hz) can be the largest frequency component
    - Subtract the mean from the original signal
  - Applying Windowing and Processing the FFT Data
    - Support Multiple windowing functions
    - Time to process the FFT data is critical to the amount of buffering / storage needed.
    - Applying Clustering if required
  - Power Consumption
    - Need to balance all the above vs the power required.
    - More power = More heat

Designing FFT into the Data Acquisition Module:

- **Challenges:**
  - Presenting the Results:
    - Large FFT block sizes mean large numbers of results
      - 32K FFT BINs = 16K Frequency and 16K Power Measurements
- **Peak Detect Mode**
  - Sort Results into list of Highest Power Frequency Components first
    - Top 32 Frequency & Power Pairs
- **User Defined Frequencies Mode**
  - User Defines specific Frequencies of interest
  - Power at those frequency points is returned
    - 8 Specific Frequencies

PCM Bandwidth Saving:

- **Sending Raw data over PCM at high rates takes up a large amount of the available Bandwidth**
- **Example 1:**
  - IRIG-106 Chapter 4 Rules Class II PCM Frame:
    - Max 16-bit Words per Minor Frame = 1024
    - Max Minor Frames Per Major Frame = 256
    - 262,144 PCM Locations
    - 512 for Syncword and 256 for SFID leaves 261,376 for Data
    - NASA Example: 8192Hz per channel requires 1024 Words per Channel, 4:1 Commutation
    - Fit 253 ICP Channels inside such a frame
    - Takes up 99.12% of the Bandwidth

PCM Bandwidth Saving:

- **Sending Raw data over PCM at high rates takes up a large amount of the available Bandwidth**
- **Example 1:**
  - IRIG-106 Chapter 4 Rules Class II PCM Frame:
    - Peak Detect Mode:
      - 32 Frequency Parameters and 32 Power Parameters Per channel
      - Same 253 Channels would require only 16,192 PCM locations, 6.19% of the Bandwidth
      - Saving of 92.93%
    - User Defined Frequencies Mode:
      - 8 Power Measurements per Channel
      - Same 253 Channels would require only 2024 PCM Locations, 0.77% of the Bandwidth

PCM Bandwidth Saving:

- **Sending Raw data over PCM at high rates takes up a large amount of the available Bandwidth**
- **Example 2:**
  - Frame Structure:
    - 8Hz, 160 WPF, 256 Minor Frames
    - 36 ICP Channels (RAW) Takes up 91% of the Bandwidth
    - 36 ICP channels, FFT Results only takes up 5.7% of the Bandwidth

PCM Frame Bandwidth Saving

36 ICP CHANNELS RAW SAMPLES

36 ICP CHANNELS FFT RESULTS

Conclusions:

- **Given the ever-increasing demand for more data in flight test applications and the associated problems for transmission bandwidth, conducting FFT analysis in real-time in the relevant data acquisition modules is possible. The challenges and trade-offs that must be made in implementing this inside the Data acquisition modules, as opposed to separate onboard computers, have been highlighted and the potential bandwidth savings are evident.**